SOURCE CHARACTERIZATION STUDY OF A PORTION OF THE SOUTHERN PORTLAND HILLS FAULT, PORTLAND METROPOLITAN AREA, OREGON

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INTRODUCTION

The Portland, Oregon, and Vancouver, Washington, metropolitan area is located in a seismically active region (Figure 1). Recent geological and geophysical studies indicate that many potentially active faults, including the Portland Hills, East Bank, Oatfield, and Frontal faults, are located in the immediate vicinity of downtown Portland and Vancouver, an urban corridor with a population of nearly 2 million people (e.g., Blakely et al., 1995; Pratt et al., 2001; Wong et al., 2000; Wong et al., 2001). Prior to this study, little was known about the earthquake potential and structural style of any of these faults, or even whether the identified faults were indeed active. The paucity of information regarding earthquake hazards beyond the historic record stems, in part, from the lack of a geomorphic expression on the land surface. Three major events have shaped and continue to shape the topography of the region. First, the 16.9 - 6 Ma Columbia River flood-basalt (CRB) flows blanketed the region, creating a regionally extensive, relatively flat volcanic terrain (Yeats et al., 1996). Second, the topography was again reconstructed during the 12-15 ka Missoula flood events (Waitt, 1985), where upwards of 40 catastrophic flood events reworked and deposited regionally up to 30 m of sediments. Finally, urbanization has reshaped and continues to shape the landscape, thus masking any surface topographic expression that may help in identifying active faulting. In addition to a reshaped surface topography, right-lateral, strike-slip displacement controls the northwest-striking faults that dominate the region (Beeson et al., 1985; Beeson and Tolan, 1990; Beeson et al., 1989; Yelin and Patton, 1991), thus minimizing any post-Missoula flood topographic relief that may indicate surface rupture from an active fault. The lack of a geomorphic expression, extensive modern surface deposits, strike-slip displacement, and urbanization makes hazard assessment difficult using typical geologic mapping methods. Measuring fault displacement by correlating changing lithologies within nearby water wells is useful, but is limited due to the poorly-defined boundary that separates modern deposits from reworked older sediments and the large variability in sediment types that comprise modern deposits. Large-scale geophysical methods (e.g., aeromagnetics, industry-scale seismic) are useful to locate faults, but do not provide the information needed to evaluate present-day earthquake hazards.

Subsurface mapping using near-surface geophysical methods is well suited for unraveling the neotectonic history of this region. The match between high-resolution geophysics and neotectonic studies in the Portland Basin and surrounding regions stems from the presence of a hard basalt basement within a few hundred meters of the ground surface, of known age, strong magnetization, and large seismic impedance contrast compared to overlying sediments. Within the basin lies interbedded fine- and coarse-grained sediments. The varying lithology within the sedimentary section provides many seismic boundaries to image, and coarse-grained flood deposits within the upper few meters suggests high-quality ground penetrating radar (GPR) imaging is possible.

APPROACH

Our approach has been to utilize multiple geophysical techniques to locate the Portland Hills fault (PHF). We have used aeromagnetics and land-based magnetics, well-

Figure 1

log data, high-resolution seismic reflection and GPR to locate the fault near the ground surface. In addition, we have been able to supplement the geophysical data with a single exposure of folded and disrupted sedmients that we correlate with Missoula flood deposits (ca. 12 – 15 ka).

We focused our efforts on the southern portion of the fault which is less urbanized and traverses low-lying areas away from the contemporary Willamette River (Figure 2). This investigtion focused on two sites bounding the North Clackamas Park investigation site (Hemphill-Haley et al., 2002). We chose the two sites because of the projection of the PHF, minimal urbanization and aeromagnetic signatures that are consistent with faulting. Additionally, we chose sites that might later be suitable as areas for paleoseimic investigations.

PREVIOUS INVESTIGATIONS

As part of a U.S. Geological Survey National Earthquake Hazards Reduction Program grant (USGS Award Number 00HQGR0023) we employed multiple geophysical methods, including high-resolution seismic reflection, ground penetrating radar (GPR), and magnetic profiling to locate the Portland Hills fault at North Clackamas Park (NCP) south of Portland (Figure 2). We also incorporated data from nearby water-wells to correlate the geophysical data and help direct the emplacement of the seismic profiles.

Two high-resolution seismic profiles at the NCP site provide detailed images of the upper 100 m of the stratigraphic section, and enabled us to locate significant offset in the Miocene-age Columbia River basalts (CRB) and overlying sediments (Figure 3). Ground magnetic profiles along our seismic transects correlate with offset and orientation in the volcanic basement, or CRB's. The magnetics, well logs, and ground truthing show that CRBs crop out near the southwest portion of the NCP site. Seismic, magnetics, and well log information indicate that basalts dip to the northeast and are observed at depths greater than 100 m to the north of the site. The seismic data show a strong amplitude, steeply dipping (greater than 20 degrees) horizon that is likely the top of the CRB sequence. Reflections from younger sediments (possibly Tertiary Troutdale to Latest Pleistocene Missoula flood deposits) also dip steeply. To the east, near the south-central portion of NCP, reflections associated with young sediments appear flat lying. This major change in dip appears within the Eocene to younger sediments. The dipping strata are imaged to within about 10 m below the land surface.

We interpret these data to represent a major splay of the Portland Hills fault that offsets post-CRB sediments. The change from flat lying CRB and younger sediments to relatively steep-dipping strata provide an indication of the fault location. The data do not, at present, provide equivocal evidence for the style of deformaton. However, the position of the offset CRB markers is consistent with a soutwest-dipping reverse fault which places the Portland Hills northeastward over the adjacent basin.
To date, evidence shows that post-CRB sediments have been faulted. If the youngest faulted sediments imaged from the high-resolution seismic reflection methods are Missoula-flood related deposits, then there has been at least one episode of coseismic surface rupture in the past 15,000 to 12,000 years.

Figure 2

Figure 3

GEOLOGIC SETTING

Earthquakes in the Pacific Northwest (Figure 1a) occur due to intraplate and interplate stresses related to active subduction of the Juan de Fuca plate along the Cascadia subduction zone and large-scale crustal block rotations within the North American plate (Wells et al., 1998). Although the largest earthquakes (M 8 or larger) occur along the subduction zone and smaller, deep earthquakes occur within the Juan de Fuca plate (e.g., the 2000 Nisqually earthquake), a significant hazard also exists from earthquakes in the upper crust of the North American plate (Wong, 1997). Upper plate earthquakes occur on crustal faults at relatively shallow depths (< 25 km) and are of particular concern to the populated areas of western Oregon and Washington, where northwest-trending crustal faults have formed as a result of the breakup and rotation of the Cascade fore arc (Wells et al., 1998). Crustal faults are known to exist beneath most of the densely populated regions of western Oregon and Washington, and because of their shallow depth, crustal earthquakes can produce severe ground shaking (Wong et al., 2000).

The Portland area is the most seismically active region in Oregon in historical times (Figure 1b). Based on the 150-year historic record, six earthquakes of Richter magnitude (M_L) 5 or greater have occurred within the metropolitan area including the damaging 1962 M_L 5 Portland and 1993 M_L 5.6 Scotts Mills earthquakes (Bott and Wong, 1993), the latter causing $30 million in damage to buildings and infrastructure in a mainly rural setting (Madin et al., 1993). An earthquake similar to the Scotts Mills sequence in downtown Portland could be devastating.

The Portland Basin contains more than 500 m of Miocene age fine-grained sediments, Pliocene-Pleistocene age coarse-grained deposits, and late Pleistocene to Recent age (12-15 ka) coarse- and fine-grained channel fill and overbank flood deposits (Swanson et al., 1993; Yeats et al., 1996) associated with the draining of glacial Lake Missoula (Waitt, 1985). The Missoula deposits are low velocity and may amplify ground shaking in the Portland Metropolitan area during a large earthquake (Pratt et al., 2001). Beneath the sedimentary cover, the stratigraphic section is dominated by Miocene and older volcanic and sedimentary units. The Portland Basin lies at the boundary between two crustal blocks that separate a compressional volcanic arc regime to the north and an extensional arc to the south (Magill et al., 1981; Wells, 1990); the basin may have formed in response to the transfer of strain between the basin bounding faults (Beeson et al., 1985; Yelin and Patton, 1991). The basin is controlled by northwest-striking faults that, on the basis of geologic relations, earthquake focal mechanisms, and potential field anomalies, have right-lateral, strike-slip displacement (Beeson et al., 1985; Beeson and Tolan, 1990; Beeson et al., 1989; Blakely et al., 1995; Yelin and Patton, 1991). The northeast boundary of the Portland Basin is controlled by the Sandy River and Frontal faults (Blakely et al., 1995; Walsh et al., 1987; Yelin and Patton, 1991). The southwest boundary of the Portland Basin is controlled by the Portland Hills Fault (PHF) and perhaps also by the Oatfield and East Bank faults (Beeson et al., 1991; Blakely et al., 1995; Wong et al., 2001).

The three crustal faults that define the southwest boundary of the Portland Basin have been identified as potential sources for damaging crustal earthquakes of M_L 6 or larger in the Portland region (Wong et al., 2000). An evaluation of earthquake recurrence

based on the historical record suggests that crustal earthquakes of M_L 6 or larger occur somewhere in the Portland region on average about every 1000-2000 years (Bott and Wong, 1993). Wong et al. (2000) showed that earthquakes from local faults present a greater hazard than earthquakes associated with the Cascadia subduction zone. The PHF, extending through downtown Portland, has been identified as the greatest local hazard (Wong et al., 2000). In a moment magnitude (M_W) 6.8 earthquake scenario on the PHF, calculated ground motions, as characterized by peak horizontal acceleration, exceeded 1g. Thus, although in its 150-year existence the Portland metropolitan area has gone relatively unscathed by damaging earthquakes, strong ground shaking generated by an earthquake on the PHF or nearby fault will have a major impact on the Portland area.

GEOPHYSICAL STUDIES

Earthquake hazards studies in western Oregon and Washington often rely on geophysical methods to identify the location and characteristics of crustal faults, since a pronounced topographic expression from faulting does not necessarily appear on the surface (e.g., Blakely et al., 1995; Johnson et al., 1999). The absence of pronounced surficial features typically considered indicative of high slip rate fault activity, such as alluvial scarps, offset and aligned drainages and tonal, vegetation lineaments, does not preclude this fault from being a significant seismic source. This can be attributed to surficial deposits that consist of modern flood sediments, a considerable amount of urban development, and the possibility that a significant portion of lateral slip occurs on the fault. Numerous industry seismic reflection surveys in the region were acquired in the past exploring for oil and gas deposits. Published results from these surveys (e.g.,Werner et al., 1992) document vertical offsets in the basement rocks and suggest that younger sediments are also offset. Regional aeromagnetic studies (Blakely et al., 2000; Blakely et al., 1995) have identified lineaments that correlate with crustal faults, including the PHF. Blakely et al. (1995) identified a magnetic lineament associated with the PHF as a long-wavelength dominated signal to the east separating a short-wavelength dominated signal that appears to the west. Recent regional seismic reflection surveys that have focused on neotectonic studies (e.g., Liberty et al., 1999; Pratt et al., 2001; Wong et al., 2001) document offsets in Plio-Pleistocene age sediments above basement rocks. Prior to this study, Holocene-age disruption of sediments in the Portland metropolitan area was inferred, but not directly documented with geophysical studies and trenching.

The PHF had been identified and located only on the basis of large-scale geomorphic features such as the asymmetric anticline and fault line escarpment of the Portland Hills (Madin, 1990), from an aeromagnetic survey (Blakely et al., 1995), and from local well logs. The principal objective of our investigation is to better locate and characterize the PHF and provide a site to fully characterize the temporal and behavioral characteristics with a paleoseismic trench. The PHF is mapped for over 25 km, and possibly extends a considerable distance beyond its mapped boundaries. We focused our current investigations at two field sites. The Clackamas River Terrace (CRT) site was selected because it contains an extensive Pleistocene fluvial terrace that potentially spans the southeastern extension of the PHF. We completed a second survey at the Rowe Middle School (RMS) site to focus our investigation on deformation of late Pleistocene

and younger Missoula flood sediments and modern alluvium to determine that the PHF is presently active.

Clackamas River Terrace Site

      This site is located south of the North Clackamas Park site (Figure 2) along the north bank of the Clackamas River. We selected the site based on the southward projection of the fault as imaged by Line 2 of (Pratt et al., 2001) and by the presence of a large, undeveloped fluvial terrace.. The terrace geology probably consists of Missoula flood silt, gravel and "channel facies" sediments deposited over Troutdale Formation. Although the age of the terrace surface is not well-constrained it is probably Holocene and thus the upper few meters of sediment are likely of similar age. The terrace is a northeast-trending set of about five surfaces separated by risers that vary in height from about 1 m to 4 m. The combined surface is approximately 1.75 km long and 200 to 400 m wide (Figure 2 a and c). Currently, the terrace is being used for small-scale farming.

      We conducted site geologic reconnaissance of the terrace surfaces, ground- and river-based magnetometer surveys and GPR surveys across the majority of the width of the terrace site. Our initial investigation consisted of a ground- and river-based magnetometer survey (Figure 4). The ground based survey was constructed along the central part of the terrace. The southwesternmost part of the terraced was unavailable due to land access problems. We used the river-based survey to cover that portion of the terrace were permission was not granted. We accomplished the river-based survey by using an inflatable raft equipped with a non-metallic frame and oars. We conducted the survey at low water levels so that the transmitter and receiver were relatively close to the river bed. The results of both survey are shown in Figure 4b. A significant drop in the magnetic signature appears in the southwestern portion of the four survey legs (Figure 4b). This drop corresponds with an abrupt change in the course of the Clackamas River from an approximately S50°W azimuth to almost due south (Figure 4a).

      We also gathered GPR data along 3 transects within along the terrace (Figure 5a). Again, we did not have access to the southwesternmost portion of the terrace to gather data. The three GPR profiles do not provide conclusive evidence for faulting within the terrace deposits (Figure 5b). Significant reflections (for example along Profile 1 at location 50 at a depth of 4 to 6 m) are likely caused by large clasts.

      Based on our investigation of the Clackamas River Terrace site we concluded that the Portland Hills Fault, if present, was likely at or beyond the southeastern limit of the terrace. The abrupt bend in the Clackamas River at this location may be structurally controlled by the fault (Figure 4a). Due to lack of access and uncertainty regarding the location of the fault we concluded that the CRT site was not suitable for additional study and an unlikely site for paleoseismic investigation.

Rowe Middle School Site

      During our search for a site to locate Holocene deformation along the PHF near NCP, we identified an active construction site approximately 1.5 km along the inferred strike from NCP (Figure 2a) at a middle school with adequate open space for a geophysical survey. An engineering borehole (B-4) at RMS (Figure 2b) shows

Figure 4

Figure 5

unsaturated silty sands to sandy gravels in the upper 11 m of the section, with a clay aquatard at the base of the sand sequence. The sedimentary sequence from the borehole is consistent with Missoula flood deposits. Coincidentally during construction, we observed a retaining wall excavation along the eastern boundary of the school (Figures 2b and 6) that revealed folded and faulted sediments. Although we could only occupy the trench for a two-day examination, we identified seven rhythmites, or flood events (Missoula flood deposits) that document more than one meter of shortening over the 36 m long trench (Figure 5a, Madin and Hemphill-Haley, 2001). Within the 1.5 m deep trench, several deformed horizons truncate against an anticline (Figure 7a). Above this unconformity, sediments are also folded, suggesting that the excavation trench documents two separate shortening events within the flood deposit sequence (Madin and Hemphill-Haley, 2001). Although the resources were not available for a complete paleoseismic investigation, ample evidence appears to suggest Quaternary motion on the PHF.

We conducted geophysical investigations at RMS along the backfilled trench that included a ground-based magnetic survey, multiple frequency (50 and 100 MHz) GPR surveys, and a high-resolution seismic survey to focus on the deformation within the top 20 m of the site. The profiles extend beyond the confines of the trench to correlate the geophysical results and deformation observed from NCP to that observed in the trench.

We duplicated the acquisition parameters for the ground-based magnetic survey from NCP. Our magnetic survey (Figures 8a and b) extends only 125 m, but shows a 700 nT anomaly (Madin and Hemphill-Haley, 2001) that is similar to the observed anomaly at NCP within the zone of deformation (Figure 3). The magnetic anomaly suggests a topographic expression appears on the CRB/sediment boundary similar to that observed at NCP and that the deformation beneath the trench is likely similar to the deformation observed at NCP.

Next we conducted a series of GPR experiments at the Rowe site (Figure 8). We acquired radar data with a Sensors and Software Pulse Ekko 100 system with a spatial sampling of 0.2 m for several hundred meters across the trench. The radar survey required a small spatial sampling at this site to adequately image the tight folds observed in the trench (Figure 7). We acquired our profiles approximately 4 m west of the trench location (Figure 8) to image native materials adjacent to and below the logged trench. The construction crew scraped the ground surface adjacent to the trench and applied a gravel surface to allow construction vehicle access along a makeshift road (Figure 8). This flat-lying homogeneous near-surface cover provided ideal conditions for GPR acquisition near the trench.

Figure 7 shows the 100 MHz GPR image adjacent to the trench. We observe a pattern of reflections that mimic the trench log with imaging depths up to 2.5 m. We also acquired a 50 MHz profile that shows a similar pattern of deformation to 5 m depth (Figure 7). The form of the folds are clearly expressed by the dipping reflections showing an anticlinal and synclinal pair. The hinge of the buried portion of the anticline appears more sharp-crested than the exposed sediments indicate. This may provide evidence for a fault at depth that progresses upward as a fold similar to the form of a fault propagation fold. In addition to the anticlinal and synclinal pair, additional deformation appears to both the northeast and southwest. While the trench log documents at least one meter of shortening along the length of the trench, the GPR profiles clearly show that the amount of shortening is considerably greater across the PHF.

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Figure 6

Figure 7

Figure 8

Although we acquired GPR profiles that extend beyond the length of the trench and construction site, data quality and signal quality away from the construction site diminish. We attribute this to the conductivity of the modern alluvium. Figure 8c shows that the GPR profiles, trench, and access road for construction actually cut a topographic high that may be fault related (similar to the folds observed in the trench and GPR). Once the GPR profiles extend onto the modern alluvium and native soil, our data quality suffers. This suggests that although the GPR results clearly document and characterize deformation at the Rowe site within the upper 5 m of the ground surface, we may not be able to extend GPR methods to sites that contain a modern, highly conductive surface layer.

To extend the imaging depth and extent of the GPR data acquired at the RMS site, we also acquired a high-resolution seismic reflection survey to image the deformation in the top 20 m (Figure 7d and 8c). We acquired a seismic reflection line that extends beyond the lengths of the successful GPR image and trench log, but not as long as the NCP survey, due to cultural barriers that included a tennis court, a busy highway, and houses (Figure 6). We acquired the seismic reflection data with the same equipment described at NCP, but we changed the station spacing to 0.5 m to allow additional fold at shallow depths and to account for slower seismic stacking velocities (< 400 m/s) above the vadose zone. The acquisition parameters provided split spread shot records, a 0.25 m CMP station spacing, and a 60-fold reflection section parallel to the trench. Due to the construction and modification to the surface materials adjacent to the trench, we opted to drill holes for our geophones in a sidewalk that was slated for removal during a subsequent phase of construction (Figure 8c). Beyond the construction zone, we placed our geophones in native materials. We chose to place our geophones in the sidewalk rather than the adjacent gravel road to provide a uniform surface medium for wave propagation and geophone plants, and to avoid construction traffic that frequented the access road along the trench. The signal quality from the shot gathers (Figure 8d) and the stack remains continuous both on and off the concrete sidewalk (Figure 7). Seismic velocities are consistent with unsaturated sediments in the upper 15 m below trench depths (Figure 8d).

The 150 m seismic profile shows a strong amplitude coherent reflection section from 1 to 15 m depth that mimic both the GPR and trench results. A strong amplitude reflection appears at 8 to 12 m depth with a velocity of 300 m/s (Figure 7). The reflection correlates with a change in lithology from sand-dominated sediments to clay, as observed from engineering borehole B-4 (Figure 7d). Additional coherent reflections appear both above and below this horizon (Figure 7d) that may correlate with a change from silty sands to sandy gravels (observed in B-4), with the reflections above the clay that strongly mimic the character of the GPR images and the trench. Several folds appear at depth along the transect and deformation extends beyond the length of the trench. The geophysical images suggest deformation that we logged from the temporary trench does not represent the complete strain history of the PHF.

DISCUSSION

Prior to this study, little was known about the temporal and behavioral characteristics of the PHF. However, during our investigation, we conducted extensive high-resolution geophysical surveys to document more than 100 m of vertical offset and tilting of Miocene-age basalts and folding and faulting of Pliocene to Recent age sediments. We logged a temporary construction excavation across a portion of the PHF that provides direct evidence for large scale folding and faulting of ca. 12-15 ka Missoula flood deposits. Our geophysical studies directly map the deformation observed in the trench and extends the zone of deformation on Missoula flood deposits at least 100 m. If we infer that the deformation at the RMS and NCP sites involve the same age sediments, a more than 400 m wide zone of deformation is observed across the PHF.

Three high-resolution geophysical methods that follow regional geophysical and geological surveys have shown significant value in uncovering a buried active fault in the Portland/Vancouver metropolitan area. Ground-based magnetic surveys, in conjunction with the regional aeromagnetic counterpart, help clearly identify the magnetic signature associated with offsets in Miocene-age and older volcanic rocks. The regional aeromagnetic survey (Blakely et al., 1995) clearly identifies the PHF from a lineament that correlates with the mapped location of the PHF, although the dominant source of the aeromagnetic lineament is not likely from offset CRB, but from offsets of deeper magnetic sources (Eocene-age volcanic rocks) with a greater vertical offsets (Blakely et al., 2000; Liberty et al., 1999). The high-resolution ground-based magnetic surveys contain considerably greater detail for identifying the zone of modern deformation, and the amplitude and wavelengths associated with the high-resolution ground-based surveys more likely represent the magnetic signal from CRB offsets depths of less than a few hundred meters. Both aeromagnetic and ground-based magnetic methods help identify the location of potentially active faults, but the deformational style and timing of faulting cannot be extracted from the magnetic signal. A further difficulty with ground-based magnetic surveys for this region is the cultural noise and restricted access to magnetic profiling due to urbanization near the PHF.

Our seismic reflection results clearly identify deformation of sediments and basalt within the Portland Basin. A scale-based approach to geophysical imaging has provided detailed seismic images of the upper 10 to 100 m below the ground surface at NCP, followed by a more focused seismic and GPR experiment that clearly images detailed deformation in the upper 20 m, a zone that is not clearly imaged with traditional seismic reflection methods (e.g., Steeples and Miller, 1998). Our success with seismic reflection methods starts with locating seismic profiles in a culturally quiet setting that contains the appropriate geologic target. Regional geophysical and geological surveys provide the initial site selection, followed by a ground canvas to identify the best study area. To provide significant detail when imaging the upper 100 m, we opt for high-density, high nominal fold surveys to provide detailed velocity information at a range of depths. Strong surface wave energy and slow seismic velocities limit the optimum window for P-wave reflections (Figure 4, Hunter et al., 1984). We use surface wave and normal moveout stretch mutes when processing, thus temporal fold varies from nominal fold for high-resolution seismic reflection surveys. To maintain adequate velocity information and fold for all target depths and provide confidence that P-wave seismic energy

dominates the stack, high nominal fold is required to adequately image a range of target depths.

GPR methods provide the highest resolution for imaging detailed stratigraphy within trenching depths (upper 5 m). Our approach is to integrate our seismic surveys with GPR surveys, since GPR acquisition and processing is very fast and inexpensive. Although GPR methods provide a clear picture of deformation at the RMS site, we suspect that we may not have similar success at other sites when operating on native materials, as we observed using GPR at NCP (not shown). We recommend the use of GPR for identifying near-surface deformation, however, our limited success has forced us to rely more on seismic reflection methods to identify and characterize potentially active faults.

As the magnetic profile, well logs, and ground truthing suggests, basalts associated with the Columbia River Basalt (CRB) sequence crop out near the southwest portion of both the NCP and Rowe sites. Seismic, magnetics, and well log information confirm that the basalts dip to the northeast and are observed at greater than 100 m to the north. The seismic data show a strong amplitude, steeply dipping horizon that is likely the top of the CRB sequence. Reflections from younger sediments (Tertiary Troutdale to Latest Pleistocene Missoula flood deposits) also appear to steeply dip, and are highly deformed. To the northeast of the fault zone, all reflections associated with young sediments appear flat lying. The magnetic data also suggest that away from the fault zone basalt appears at depth and the surface does not significantly vary. This suggests that the Portland Hills fault zone extends at least 400 m with a style of deformation that is consitent with a strike-slip fault with a minor dip-slip component. The amount of shortening documented within the trench is consistent with at least 2 major earthquakes within the last 12-15 ka, thus classifying the PHF as an active fault. We document that shortening of Missoula-related sediments extends beyond the length of the trench, therefore the amount of strain that appears across the PHF is greater than what the trench log has recorded. If we can document that 12-15 ka sediments are deformed across the width of the fault zone (> 400 m), seismic hazards for the region may be significantly greater than we have reported.

The Rowe Middle School property is not suitable for excavation of a trench suitable for paleoseismic investigation because of a lack of undisturbed land on the property. We have conducted preliminary seismic reflection at another site (Figure 6 – Ceheghino Farm) to assess its suitability for extended investigation. Our conclusions suggest that the PHF is located beyond the extent of the property, likely beyond its southwest corner (Figure 6). We are also evaluating an additional relatively undeveloped property that appears more aligned with the PHF near Rowe Middle School (Figure 6 – see Kopp-Harley property).

CONCLUSIONS

We integrated surface and airborne magnetic, seismic, and GPR surveys, with well logs, geologic maps, and a temporary excavation trench to show that the PHF is active. Deformation consistent with at least 2 major earthquakes in the last 12-15 ka. shows that the PHF is a major hazard that faces the Portland metropolitan area. We show that high-resolution geophysical surveys provide detailed images of deformation within

an active fault zone. A scaled approach to subsurface imaging provides us with the geologic framework for potentially active faults. Subsurface information using high-resolution geophysics provide detailed information that geologic maps and regional geophysical surveys cannot deliver. The limitation of surface mapping methods stems from a surface topography that has not maintained a cumulative geologic record of faulting, the dominant strike-slip component of regional faults, and large deposits of young, catastrophic flood events (Missoula floods). The success of high-resolution geophysical surveys stems from a large magnetic and seismic contrast of the sediment/basalt contact within the upper few hundred meters below Portland and contrast in seismic and electromagnetic properties of sediments that fill the Portland Basin. We plan to continue our investigations by using high-resolution geophysical surveys to locate and install a new paleoseismic trench across the PHF to more clearly determine the style and history of faulting.

ACKNOWLEDGEMENTS

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